LEWIS
IN-27-CR
261648
21P

THE UNIVERSITY OF AKRON

POLYMER ENGINEERING CENTER

NCC3-52

(NASA-CR-186324) RHEO-OPTICAL APPARATUS FOR MEASUREMENT OF STRESS FIELD IN FLUID CHANNEL FLOW (Akron Univ.) 21 p

N90-70450

Unclas
00/27 0261648

An introduction to .....

APEC

COLLEGE OF ENGINEERING
AKRON, OHIO 44325 U.S.A.
TEL: (216) 375 - 6865

Rheo-Optical Apparatus for Measurement of Stress Field in Fluid Channel Flow

by

A. I. Isayev

Polymer Engineering Center
University of Akron
Akron, Ohio 44325

in Cooperation with

R. C. Hendricks
NASA Lewis Research Center
Cleveland, Ohio 44135

Prepared for:

NASA Lewis Research Center
Cleveland, Ohio 44135

Attention: Mr. R. Boyd Bane Grant Officer

August 1987

Contents

Abstract

Rheo-optical apparatus has been developed for nonintrusive measurements of the stress field during flow of low viscosity fluids in the two-dimensional channels. The apparatus consists of a rheometer with the optical testing cell, polarization-optical system and a PC/AT based computer system for optical image analysis. Several experimental runs have been conducted on 20% polystyrene solution in Tetraline flowing through the testing cell having planar contraction and expansion. Preliminary results of the stress measurements have been reported. Further theoretical and experimental work is required in order to get more detailed information. The developed apparatus is useful to test various designs of fuel propulsion system.

Introduction

Flow of polymeric solution results in the simultaneous development of shear and normal stresses. These stresses introduce orientation of macromolecular chains which are dependent upon the rheological and relaxation properties of the polymeric solutions, geometry of the channel and flow conditions. Nondestructive measurements of orientation and stresses are important since they allow one to quantitatively evaluate the behavior of fluid in channels of particular geometry.

The major goal of the present report is to develop the rheo-optical apparatus for measurements of stress field in two-dimensional channel flow of polymeric liquids having low viscosities, and show feasibility of its use for evaluation of stresses in channels having both contraction and expansion. Initial test of this apparatus is conducted using low viscosity polymeric solution, exhibiting behavior close to Newtonian.

Background of Method

Most simple stress and birefringence distributions in flowing polymeric solutions can be measured by means of rheo-optical methods which have found wide application in recent years (1). This application is based upon two stress-optical rules for viscoelastic media (2). For the case of shear flow the first of these rules states that the birefringence Δn is linearly proportional to the principal stress difference.

$$\Delta n = C\Delta\sigma$$

where

$$\Delta n = R\lambda/W$$

and

$$\Delta\sigma = 2\,\tau_{max} = \sqrt{(\sigma_{11} - \sigma_{22})^2 + 4\sigma_{12}^2}$$

Where C is the stress-optical coefficient of the liquid, τ_{max} is the maximal tangentional stress, $\sigma_{11} - \sigma_{22}$ is the first normal-stress difference. σ_{12} is the shear stress, R the number of fringes or relative retardation. λ the wave length of light and W the path length of light through liquid. The second of these rules states that the orientation of the optical axes, χ_o, and that of the principal stress, χ_s, coincide:

$$\chi_o = \chi_s = \chi$$

where χ is the extinction angle.

In recent years, the present author and his co-workers (3-7) have carried out substantial research by using the rheo-optical technique for high viscosity polymeric melts. In particular, they studied (i) a one-dimensional unsteady channel flow (6), (ii) stationary one-dimensional oscillatory shear flow (5) and (iii) stationary two-dimensional contraction or expansion flow (3,4,7). In the former case, the time-dependent gapwise birefringence distribution is measured following a sudden imposition of pressure gradient. The results are compared with the theoretical predictions following from numerical simulation based upon viscoelastic constitutive equation. In the case (ii), an applicability of the stress-optical rule to oscillatory flow is established. In the case (iii), pressure drop, elongational stresses along the centerline and gapwise birefringence distribution are measured and large differences in those values are observed between contraction and expansion flow. A further extension of this technique to low viscosity non-Newtonian and possibly Newtonian fluids flowing in channels with both contraction and expansion is needed.

Apparatus and Materials

The developed rheo-optical apparatus consists of a rheometer, a polarization-optical system and a PC based computer system for image analysis. Schematic sketch and photograph of this apparatus is shown in Figure 1 and Figure 2, respectively. The rheometer consists of system of transparent plastic pipes having diameter 1.27 cm. Fluid circulation was provided by a positive displacement rotary gear pump driven by a AC motor. The motor rotation speed is controlled by an adjustable frequency controller Accutrol 110/Westinghouse. This pumping system provides a uniform flow rate in a range of 45.7 ml/sec to 653.1 ml/sec. Liquid was forced through a working cell with two optical windows, made of stress-free fused quarz silica. This cell includes a channel with a contraction and an expansion part. The schematic sketch and dimensions of the test channel are shown in Figure 3.

The optical system consists of high pressure mercury light source (Model 66059/Oriel), green filter (λ = 546.1 nm), and rotatable polarizer and analyzer and two quarter-wave plates. The polariscope elements were mounted on vertical rods. The light beam is viewed with a video camera and the optical output is shown on a video monitor.

Developed computer image-processing system includes the following combination of software and hardware. Hardware includes: 1) An IBM PC/AT with a composite and an analog monitor; 2) IVG-128 Image-grabbing board from Data-Cube Inc; 3) 3.0 Mega bytes RAM expansion memory allowing to upgrade total memory to 3.5 Mega bytes.

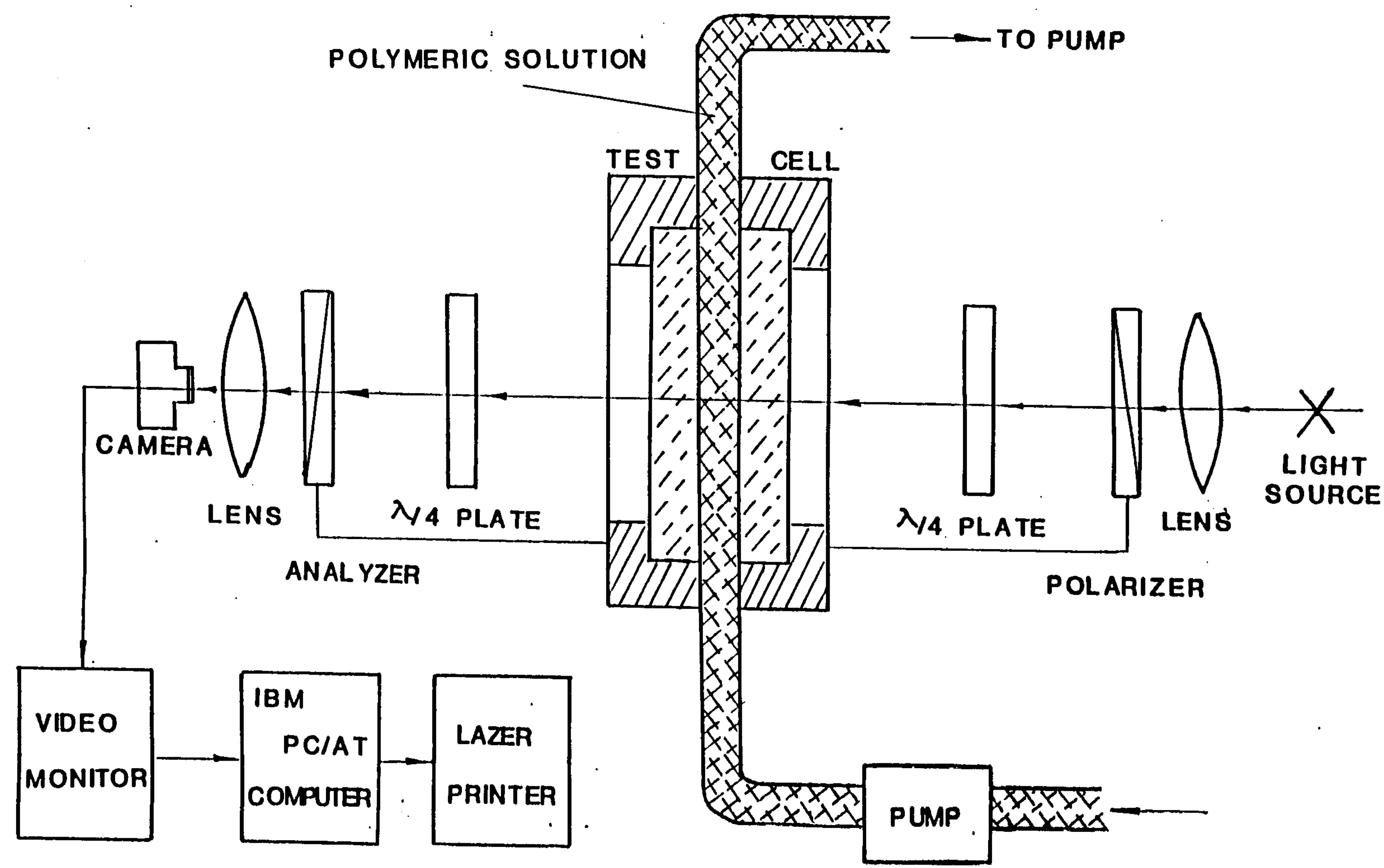


Figure 1. Schematic sketch of the rheo-optical apparatus.

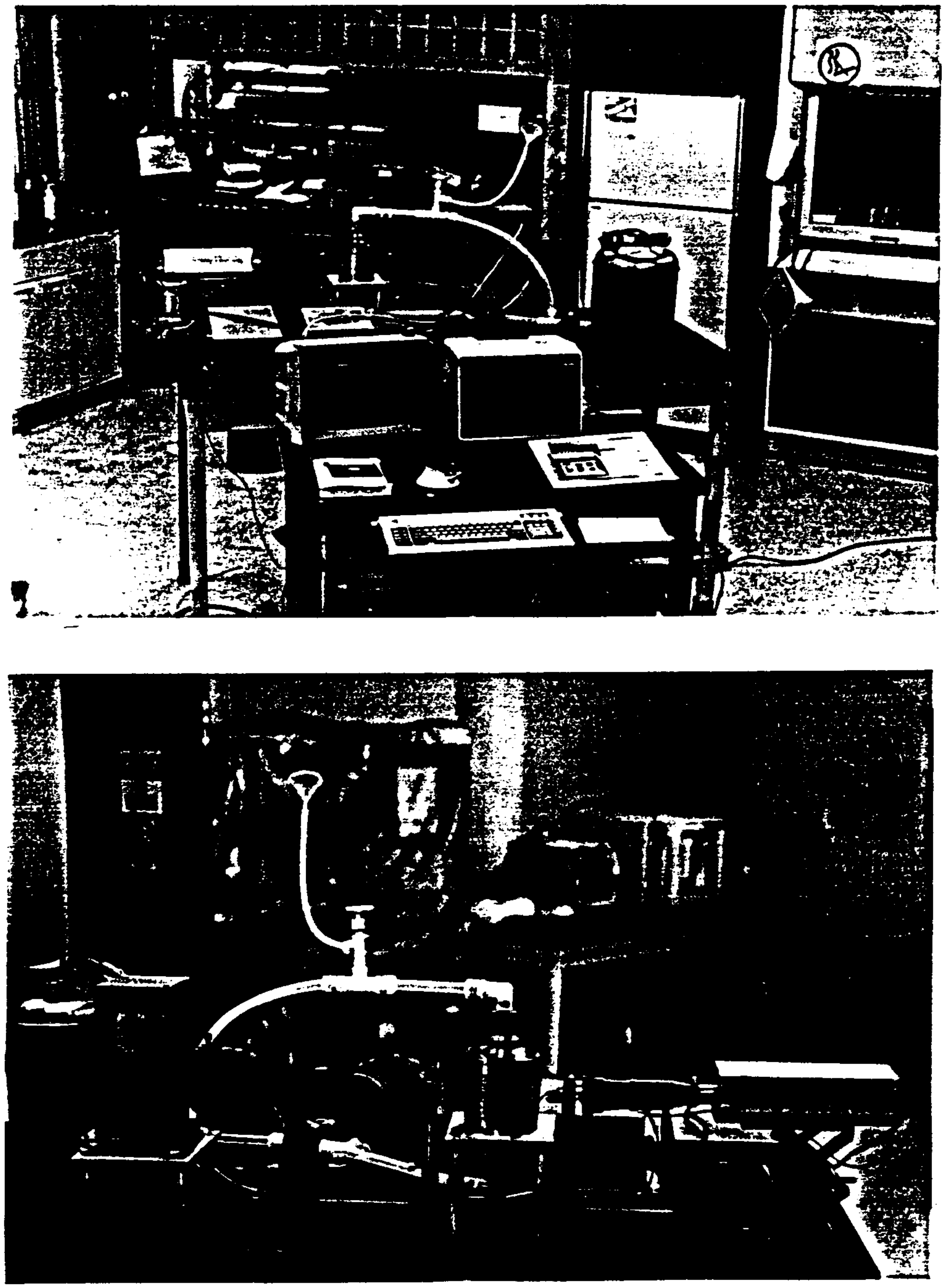
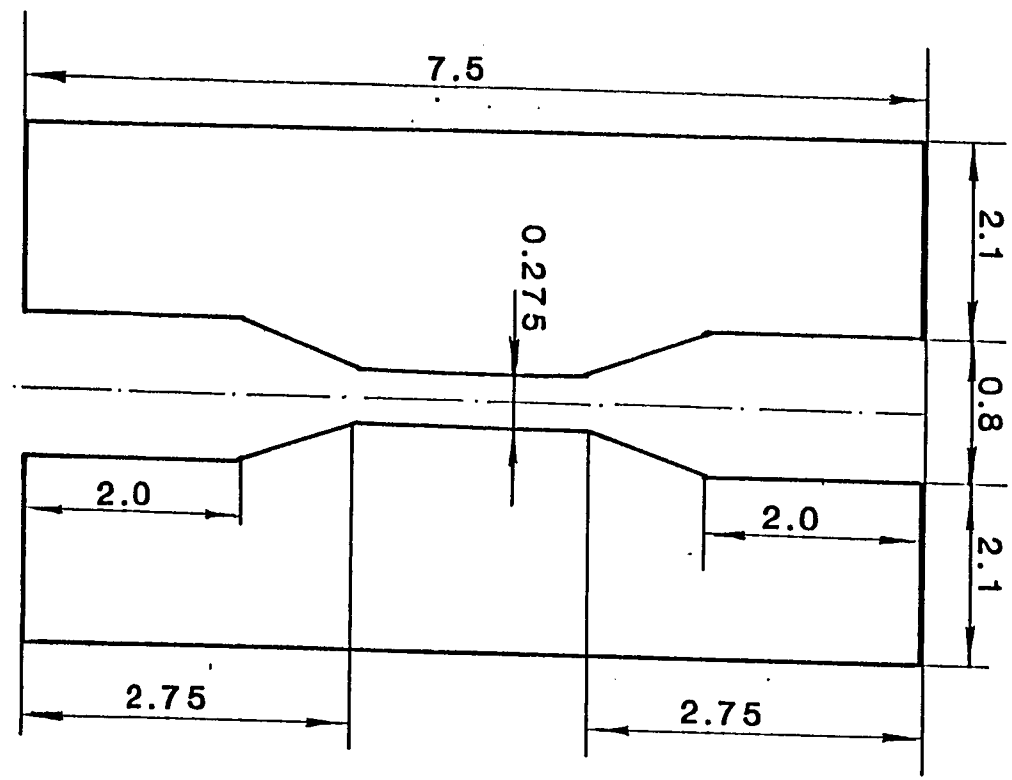


Fig. 2   Photographs of Apparatus.



WIDTH : W = 5.08 cm

Figure 3. Schematic sketch of the channel.

Software consists of: 1) Image-pro by Media Cybernetics. This is an image processing/analysis package; 2) Dr. Hallo II by Media Cybernetics. This is a graphics package used to customize Image-pro; 3) Laser printer module for Image-pro; 4) Abovedisk by Teleware West, which simulates extended memory specification (EMS) to expanded memory (for example, a RAM disk).

A frame of video image was grabbed employing video grabbing board and Image-pro. The obtained picture is then processed to achieve maximum clarity. Then necessary measurements are performed on the picture. If needed, a hardcopy of the image is obtained using an HP laser printer.

The test fluid was a 20% and 30% by wight solution of polystyrene (685-26-W/DOW) in the solvent, 1,2,3,4, - tetrahydro - naphthalene (Tetraline/Eastman Kodak). A choice of this solution is due to its high optical sensitivity. The stress-optical coefficient of this solution is 5030 Brewsters according to reference 8.

Experimental Procedures

The rheo-optical experiments are sensitive to some external distortion. In order to do the reliable experimental measurements the following procedures are adopted.

At first the optical system is aligned. In order to do so, lamp is adjusted such that a maximal possible collimation of light beam is obtained. Both lamp and video-camera are located in the symmetry plane of the test cell, and the center line of the optical bench is set perpendicular to the symmetry plane of the optical cell. Planes of polarizer, analyzer and two quarter-wave plates are chosen perpendicular to the center line of the optical bench. If the analyzer axis is set at 90° from the polarizer axis, extinction will be observed since their respective planes are crossed. In this case, the obtained image is so called dark field. Rubber pads are placed under every elements of the apparatus. Apparatus is placed on the experimental table as one unit. All measurements were performed in dark field at room temperature ($24^{\circ}C$).

Leakage is another problem which encountered in experimental measurements. Namely, the solution leaks out from the test cell and pump. The cell surfaces, which directly come into contact with solution, are sealed by means of Teflon tape. The other surfaces are sealed with a special rubber, resistant to action of Tetraline. There was a slgiht leakage from the pump which generated some air bubbles during prolong runs. However, the experiments showed that small amount of air mixed in the solution does not effect the optical image.

Rheological Measurements

Rheological measurements were made by using Mechanical Spectrometer/Rheometrix in the steady-state mode. The diameter of cone and plate is 2.5 cm. cone angle is 0.1 rad. All measurements were performed at room temperature. Shear stress versus shear rate curves for two solutions are shown in Fig. 4. It can be seen that behavior of 20% solution is close to Newtonian in wide range of shear rate, while 30% solution shows some appreciable non-Newtonian behavior.

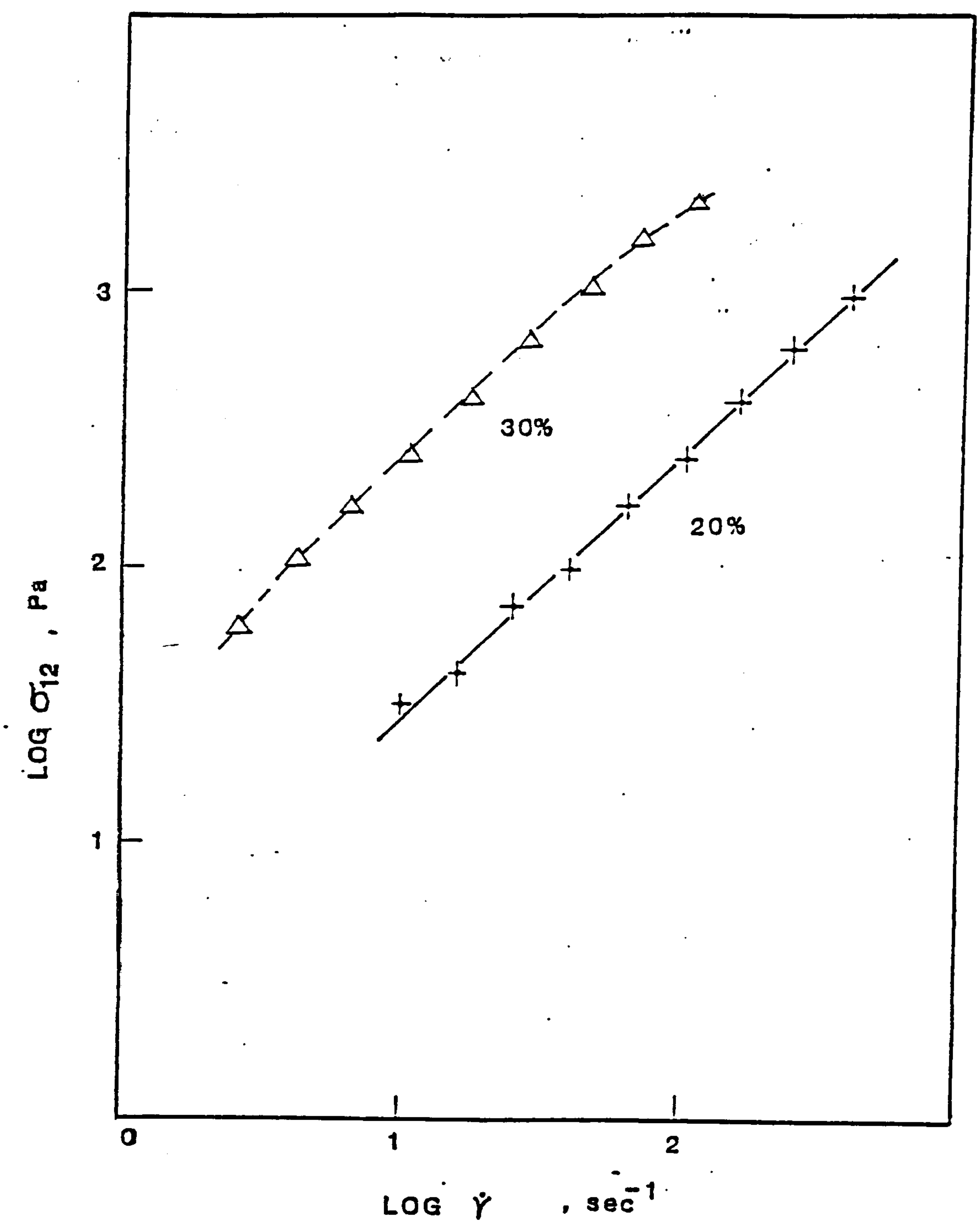


Figure 4. Shear stress versus shear rate for 20% and 30% by weight solution of polystyrene in Tetraline.

Optical Measurements

The pictures were taken at different flow rates. Flow was directed from the bottom to the top of the channel. A hardcopy of optical image obtained by means of the computer image-processing system using an HP laser printer is show n in Fig. 5 for flow rate
55.5
112.9 cm^3/sec. By means of the Image-pro software, the measurements could be made accurately.

Figures 6 through 9 show typical examples of positions of the isochromatics observed in the channel during flow of 20% solution.
5
In particular, at flow rate 56.46 cm^3/sec only one fringe appears in the field (Fig. 6). As flow rate increases, two fringes are generated. The second fringe starts to appear at the corner at the converging end of the channel and at start of diverging part of the channel at flow rates 112.9 cm^3/sec (Fig. 7). When flow rates increases further, fringes move toward the centerline of the channel. In fact, measurements show that at the center line of channel stress are always nonzero. Calculations show that the value of one fringe in this test cell is 2,137 dyne/cm^2. Accordingly, one knows what is stress level at these fringe locations.

Further work is needed to extend these optical measurements to channels of various geometries along with a detailed measurements of the pressure distribution. In addition, calculations of the stress field have to be performed based upon the finite element method in order to compare results of experimental measurements with theoretical predictions. This would allow us to design more efficient delivery system for fuel propulsion.

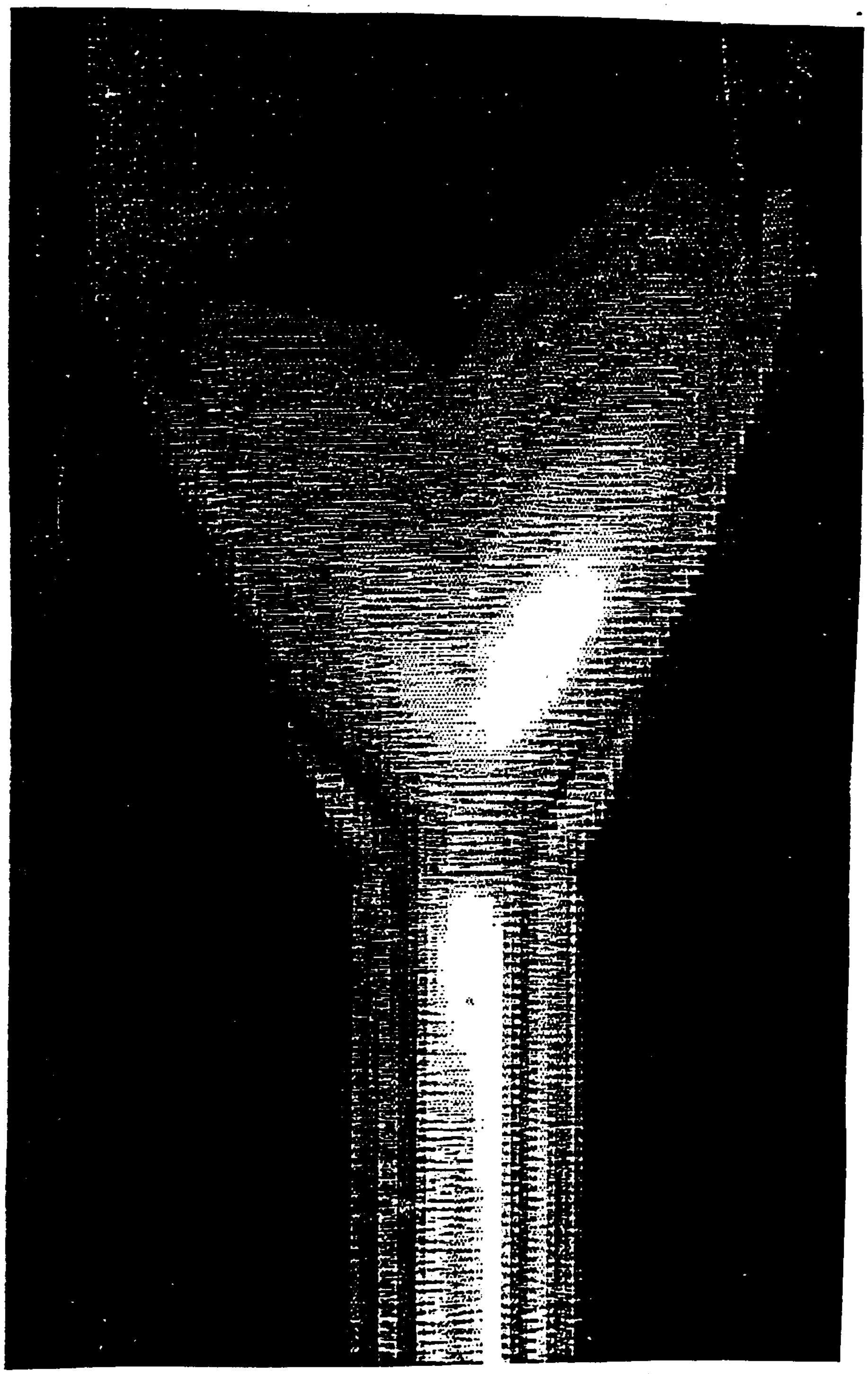


Figure 5. A hardcopy of optical image obtained by computer image processing system at flow rate 56.5 cm^3/sec.

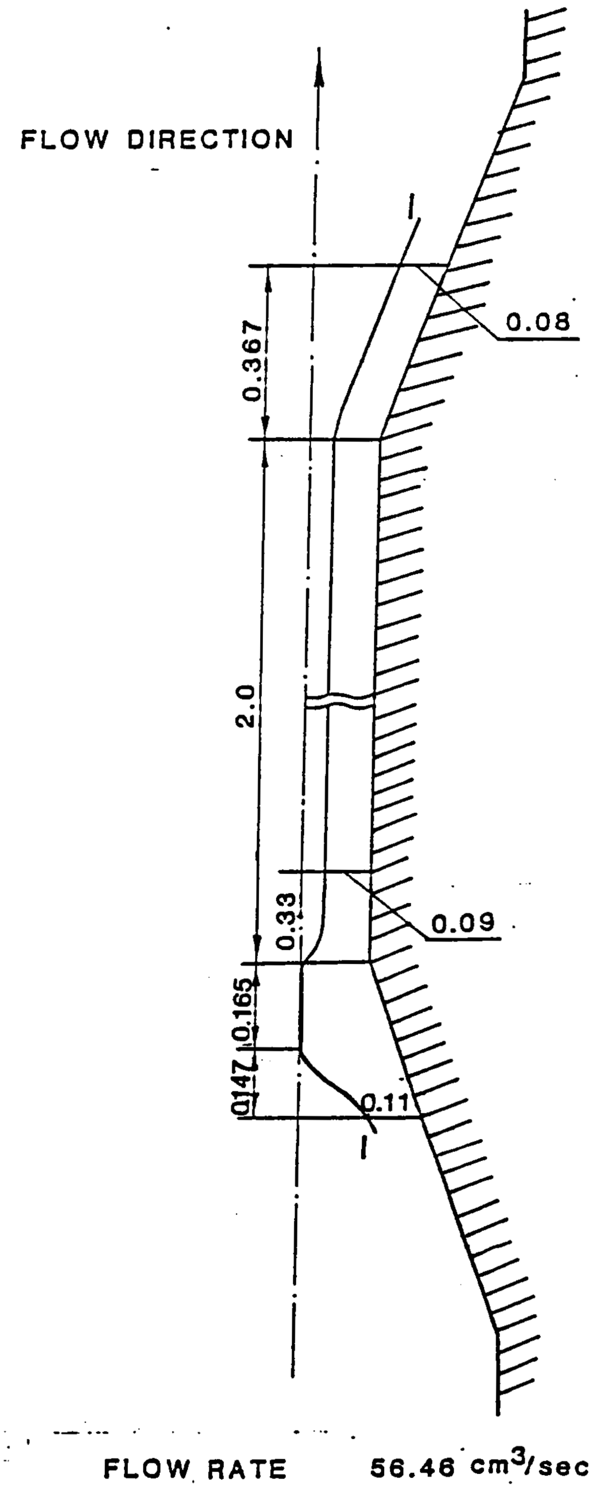


Figure 6. Isochromatic patterns during channel flow of 20% solution. All dimensions are given in cm.

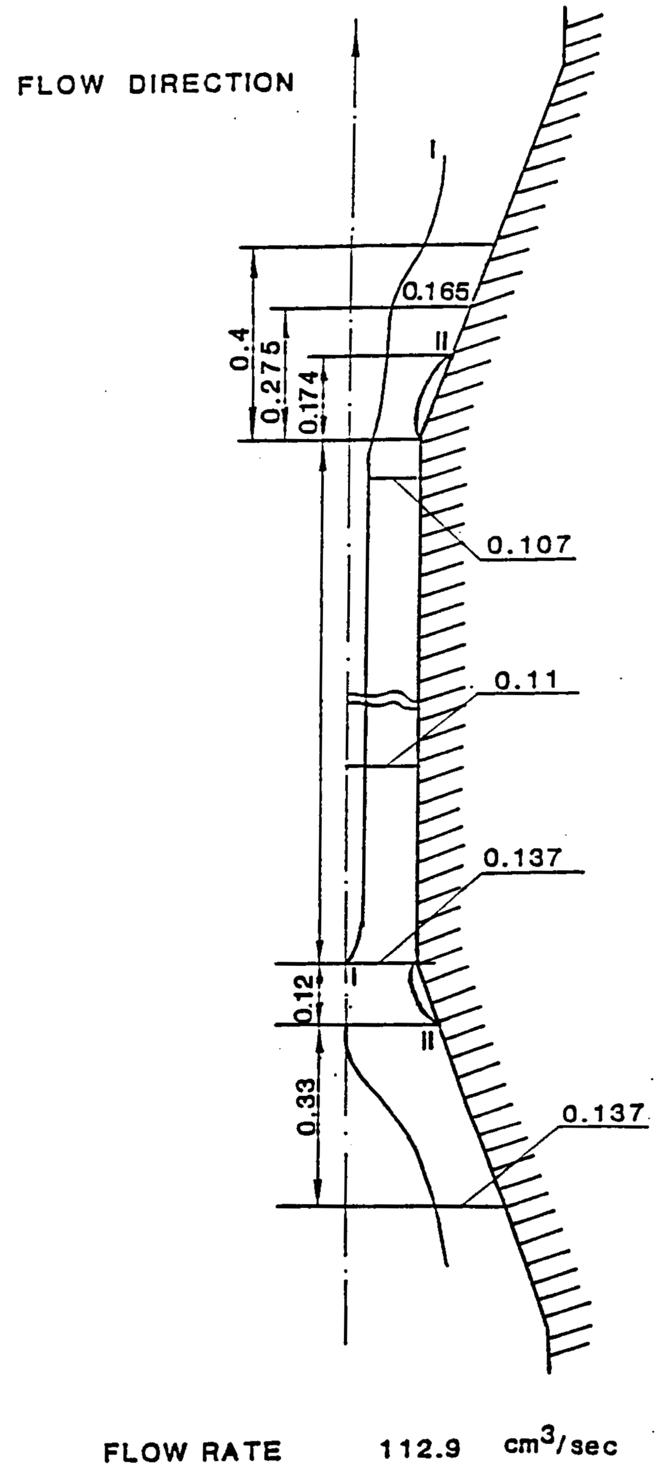


Figure 7. Isochromatic patterns during channel flow of 20% solution. All dimensions are given in cm.

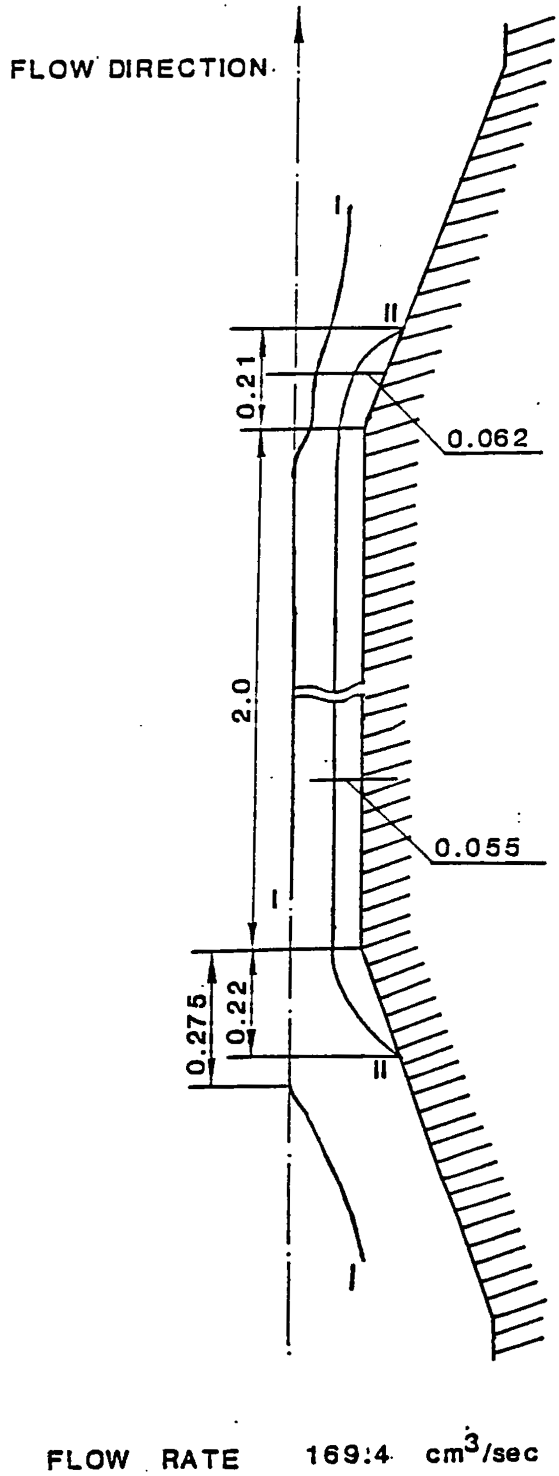


Figure 8. Isochromatic patterns during channel flow of 20% solution. All dimensions are given in cm.

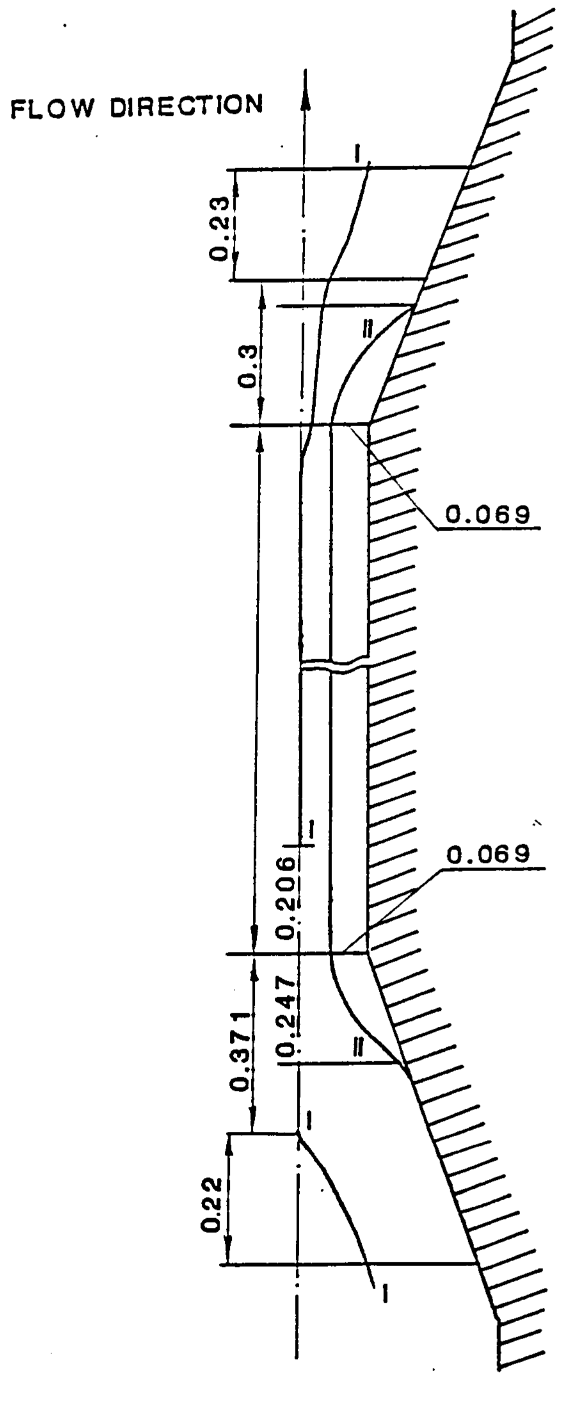


Figure 9. Isochromatic patterns during channel flow of 20% solution. All dimensions are given in cm.

References

1. H. Janeschitz-Kriegl, Polymer Melt Rheology and Flow Birefrigence, Springer-Verlag, New York, (1983).

2. A. G. Lodge, Nature 176, 838 (1955).

3. V. I. Brizitsky, G. V. Vinogradov, A. I. Isayev and Yu. Ya. Podolsky, J. Appl. Polym. Sci., 20, 25 (1976).

4. V. I. Brizitsky, G. V. Vinogradov, A. I. Isayev and Yu. Ya. Podolsky, J. Appl. Polym. Sci., 22, 751 (1978).

5. G. V. Vinogradov, A. I. Isayev, D. A. Mustafaev and Yu. Ya. Podolsky, J. Appl. Polym. Sci., 22, 411 (1984).

6. A. I. Isayev, J. Rheol., 28, 411 (1984).

7. A. I. Isayev and R. K. Upadhyay, J. Non-Newt. Fluid Mech., 19, 135 (1985).

8. W. Philippoff, Tran. Soc. Rheol., 3, 153 (1959).